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ENVIRONMENTAL BASELINE PROGRAM

NOVEMBER '74-OCTOBER '76

FINAL REPORT

EXECUTIVE SUMMARY●

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U. S. DEPARTMENT OF THE INTERIOR

PROTOTYPE OIL SHALE LEASING PROGRAM

OIL SHALE TRACT C-b

ENVIRONMENTAL BASELINE PROGRAM

FINAL REPORT

(November 1974 Through October 1976)

EXECUTIVE SUMMARY

Submitted to:

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U. S. Geological Survey
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By:

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ACKNOWLEDGMENTS

The information for this Executive Summary was condensed by Quality Development Associates, Inc. from the five volumes of the Oil Shale Tract C-b Environmental Baseline Program, Final Report, and thus represents the contributions of the technical managers, authors, review committee members, and technicians for the entire project. The efforts of these individuals are cited in the volumes to which they contributed.

EXECUTIVE SUMMARY

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1 INTRODUCTION

Oil Shale Tract C-b is a Federal Lease Tract of approximately 5,100 acres located in the Piceance Basin, in Rio Blanco County, Colorado. The land is legally described as follows:

Township 3 South, Range 96 West, Sixth Principal Meridian

Section 5: W½ SE¼, SW¼;
Section 6: Lots 6 and 7, E½ SW¼, SE¼;
Section 7: Lots 1, 2, 3 and 4, E¼ W½, E½;
Section 8: W½ and NE¼, NW¼, S½;
Section 9: SW¼;
Section 16: NW¼, W½ SW¼;
Section 17: All;
Section 18: Lots 1, 2, 3 and 4, E½ W½, E½;

Township 3 South, Range 97 West, Sixth Principal Meridian

Section 1: S½;
Section 2: SE¼;
Section 11: E½;
Section 12: All;
Section 13: N½;
Section 14: N½, NE¼.

Development of Tract C-b is governed by the terms and conditions of the Federal Oil Shale Prototype Leasing Program administered by the Area Oil Shale Supervisor, U. S. Geological Survey, U. S. Department of the Interior. The environmental stipulations attached to the Federal Oil Shale Lease require that a two-year environmental baseline field study be conducted on the Tract and one-mile surrounding area prior to Tract development. This requirement was further modified by conditions of approval issued by the Area Oil Shale Supervisor for each special program of the study. The study is referred to as the Environmental Baseline Program. The program for the C-b Tract was initiated on November 1, 1974 and completed on October 31, 1976.

During the two-year Environmental Baseline data collection period the lease required the collection and analyses of environmental baseline data in the following areas: surface water, ground water, air quality, meteorology, flora and fauna, soils, geology, and archaeology. The Environmental Lease Stipulations also required the Lessee to study and report on ecological interrelationships. The data generated in these and other disciplines during the baseline period have been fully disclosed and reported in quarterly data reports and in the Annual Summary and Trends Report, which were submitted to the Area Oil Shale Supervisor's Office. These reports are available in that office for public review and inspection. Each data report was summarized in a Quarterly Summary Report, also available for public review and inspection in the office of the Area Oil Shale Supervisor. This office is located in Grand Junction, Colorado. In total there are nine Quarterly Data Reports and eight Summary Reports; the Annual Summary and Trends Report contains an analysis of the first year's data collection effort.

The Final Report for the Environmental Baseline Program covers the two-year environmental data collection program. This program was initiated in part to satisfy the requirements of the environmental stipulations attached to the Oil Shale Lease granted by the U. S. Department of the Interior, and in part by the Lessee's desire to operate within parameters protective of the natural environment.

The Environmental Baseline Program, Final Report consists of five volumes and this Executive Summary. These volumes are: Volume I, Regional and Temporal Setting; Volume II, Hydrology; Volume III, Meteorology, Air Quality, and Noise; Volume IV, Ecology (with an accompanying Appendix Volume); and Volume V, System Interrelationships (with a Supplementary Envelope containing a User's Reference and Diagrams).

The Regional and Temporal Setting volume attempts to place the two-year baseline study for Tract C-b in a time and regional perspective. Volume II presents the results of the investigations for the hydrological system; Volume III summarizes air quality, meteorology, and noise aspects; and Volume IV discusses the ecological studies of the Environmental Baseline Program. Volume V summarizes, integrates, and synthesizes much of the environmental information collected during the baseline study program. It also provides a means which enables users to locate specific data presented in the earlier volumes. This Executive Summary is organized along the lines of the five volumes. Each chapter summarizes the findings related to each of the five volumes.

2 REGIONAL AND TEMPORAL SETTING

The purpose of Volume I is to place the two-year environmental baseline study of Tract C-b into a regional and historical perspective. In this perspective the geologic Piceance Basin is differentiated from the drainage of Piceance Creek, which is termed the Piceance Creek basin (Figure 2-1).

For each scientific discipline involved, a review of the available literature concerned with the environmental setting of the Piceance Basin was conducted. Until recently there has been very little written on various scientific treatments with respect to northwest Colorado. This lack of data has led to generalizations in the specific subject areas, and causes some difficulty in assessing the baseline vis-a-vis the regional and temporal background.

The results of the baseline study have pointed out, however, the interactions that exist between the major environmental parameters in each study area. For example, the present form and hydrology of the Piceance Creek basin is discussed in relationship to the geology of the region as well as the continental, regional, and local climatology. Climate is seen to be a function of time and also of surface form, which has been shaped by climatological factors. Throughout the course of the baseline study disciplinary interactions can be observed.

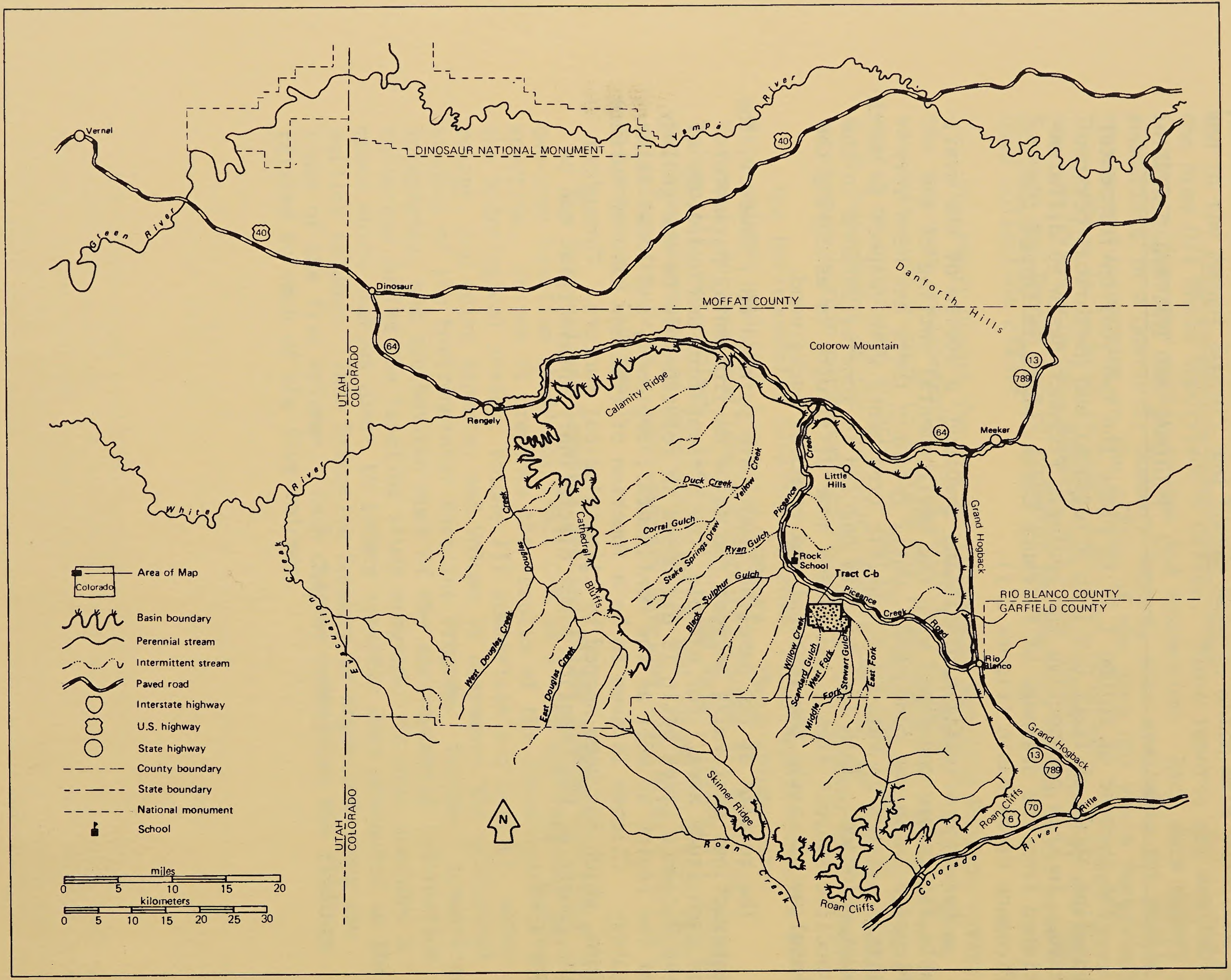

Figure 2-1 REGIONAL LOCATION MAP SHOWING OIL SHALE TRACT C-b

2.1 Physical Setting

The historical and regional study of the physical sciences includes geology, climatology, hydrology, and soils. Site specific data collected over the baseline period are presented in the volumes appropriately related to these study areas. Hypotheses developed upon the basis of the present information will be modified as monitoring programs continue.

2.1.1 Geology

Early historical geology of northwestern Colorado is one of long periods of deposition interrupted by regional uplift and widespread erosion. It is the Tertiary and later history that is most relevant to the Oil Shale Tract and to the present form of the basin. Tract C-b is located in the southeastern portion of the Piceance Creek drainage system.

The Piceance Creek basin is a NW-SE trending structural and sedimentary basin. In general it is an elevated area that is part of the Colorado Plateau Physiographic Province. Tract C-b is located on the boundary between the upland slope and basin interior subregions of the Piceance Basin.

The gently northeast dipping Green River Formation, which encompasses the oil shale zone of interest, is overburdened by the clastic Uinta Formation. Alluvial deposits, limited to major stream valleys and large draws, and colluvial deposits on valley sides and divides, cap the Uinta Formation.

In the geologic study of the Tract, abundant fracturing was found in the Uinta Formation. Fracturing and faulting are important from a pedological point of view in that fractures in the parent material provide different environments for the development of soils and subsequently the development of vegetation. Fracturing also appears to have affected river valley orientation, and may affect ground water flow.

No major geologic hazards, such as faults and landslides, were found on the Tract, though minor soil creep and slump occur in some small tributaries.

Geomorphic processes operating on the sedimentary beds, uplifted and deformed by structural and erosional processes, have developed scenic areas around the periphery of the basin. Within the basin these same processes operating on the essentially flat-lying Tertiary sediments have produced a generally monotonous series of valleys and convex ridges radiating away from the east-west running main stream of Piceance Creek and south-north running Yellow Creek.

2.1.2 Climatology

The C-b Tract is located in the semi-arid Plateau Province of western Colorado. Over the period of occupation, inhabitants of this area probably experienced periodic climatic variations. However, dendrochronology studies suggest that over the past 500 years the climate has been similar to the present.

Wide variations in precipitation, temperature, and wind movement from place to place result primarily from the varied topography. The local climate is strongly influenced by slope, aspect, elevation, soil type, and vegetation. In particular surface wind patterns and vertical temperature profiles are almost entirely dependent on local topography.

Precipitation ranging from 304.8 to 609.5 mm (12 to 24 in) per year, increases with altitude. Most of the precipitation is received in the winter as snow, with occasional monthly amounts up to 76.2 mm (3 in) occurring in the summer when convectional thundershowers bring scattered rains to the area. Frontal activity in winter brings snow, the spring melt of which causes high surface runoff as well as recharge of the ground water system. Recent precipitation records on the Tract compared with averages through the middle part of this century indicate that 1975 was wetter in the spring and early summer and drier in late summer and fall than the average for the period 1941-1970.

Minimal cloud cover and an average elevation of over 1828.8 m (6,000 ft) contribute to a high solar radiation gain during the daytime and an excessive amount of reradiation at night. The combination of high heat gains and losses along with the elevation and continentality of the area, contribute to a large diurnal and yearly temperature range.

Winds are generally west-to-east but are greatly modified by local topography. Wind velocities average 6.4 to 16.0 km/hr (4.0 to 10.0 mph).

2.1.3 Hydrology

In the semi-arid regions of northwest Colorado evaporation and transpiration losses are high. These high evapotranspiration losses combined with low precipitation make those water courses exhibiting perennial flows reliant on ground water discharge for their baseflow. Dramatic changes in the baseflow along Piceance Creek are evident from stream flow records spanning the 1972 and 1973 water years. Records from surface water gauging stations show the average yearly flow for the 1973 water year and subsequent water years is approximately twice the yearly mean for 1972 and prior water years. Such an increase in baseflow might be attributed to effects of the underground nuclear gas stimulation test known as Project Rio Blanco.

Surface waters in the Piceance Creek hydrologic basin are a mixed sulfate-bicarbonate type, with concentrations of both ions increasing from the headwaters downstream to the mouth of Piceance Creek at the White River. Discharge patterns are those expected of streams which are sustained during low flow periods by ground water discharge. Months of major flow are March through August. Most of the flow during the first part of this period is attributed to spring snowmelt. Flow during the second part of this period is attributed to ground water outflow augmented by summer storms. The ground water regime is recharged by snowmelt and contributes substantially to surface flows through discharges from seeps and springs.

Poor quality water discharged from springs in some parts of the Piceance Basin cause an increase in total dissolved solids as Piceance Creek and Yellow Creek approach the White River. The water quality in springs on the upper reaches--in the area of the Federal Oil Shale Lease Tract C-b--approximates that of ground water in the shallow "upper" aquifer and the alluvial aquifer. The quality of water in these two aquifers and in the streams, although moderate in dissolved solids, is suitable for agricultural use.

Similar concentrations of most constituents in ground water samples from the upper aquifer and from the alluvial aquifer suggest recharge by the upper aquifer through the alluvium. High concentrations of dissolved solids in the lower aquifer and the high dissolved solids content in some spring waters suggest communication, most probably along fault traces between the surface and the deeper aquifer.

Ground water samples from Tract C-b, when compared to springs and other surface water sources, suggest that there are no conduits between the lower aquifer and the upper aquifer or the surface.

2.1.4 Soils

Seven soils occur on Tract C-b and the surrounding study area. The most predominant soil is the Rentsac series. This soil formed in residium on broad uplands from fractured sandstone parent materials. The Redcreek series, which is closely associated with the

Rentsac, formed on ridgetops and narrow uplands over massive sandstones. The shallower Redcreek and the Rentsac together make up a major soil complex. Both soils are associated with pinyon-juniper and Douglas-fir forests. The Redcreek series also underlies bunchgrass communities.

Other upland soils include the Forelle and Piceance series. These soils are moderately fine textured and deep; they formed in residium and were altered by eolian deposits. Upland sagebrush communities are strongly associated with these soils.

Bottomlands are dominated by the Glendive series. This is a deep soil formed from coarse alluvial materials. The Glendive series supports big sagebrush communities and is also associated with agricultural meadows. Other bottomland soils are the Rivra and Hagga series. Rivra is found predominantly on alluvial fans and cones. Vegetation types associated with this soil include greasewood and big sagebrush. Hagga is a deep soil occurring in alluvial areas. This soil is associated with riparian areas and agricultural meadows.

Soils on Tract C-b are generally cool or cold and have limited water available to plant growth. Soils are also low in fertility and tend to be high in toxic substances. Toxicity is particularly high in bottomland soils. Soil productivity studies show that the upland soils are capable of supporting plant growth to a greater extent than bottomland soils. Of the upland soils the Redcreek-Rentsac complex is the most productive.

2.2 Biological Setting

The biota of the Piceance Creek basin and surrounding region occurs as a complex mosaic of vegetation and habitat types which conform closely with the ridge and valley topography of the area. In a broad ecological sense, the basin is part of a large expanse of pinyon-juniper vegetation that extends intermittently from southern Wyoming to the southwestern U. S., through Colorado into Utah, New Mexico, and Nevada. Floristically, the Piceance Creek basin lies in the transition zone between the cold desert floras of the Great Basin and Intermountain West and the montane forests of the Rocky Mountains. The major habitat types occurring on Tract C-b are found throughout much of the Piceance Basin.

Historical accounts from 1776 indicate that the upland vegetation of the area was much the same then as now, except for some woodland areas which have been chained in an attempt to improve rangelands. Valley bottoms were subject to overgrazing practices of early settlers. The bottomlands of major drainages are now primarily used as hay meadows. Early accounts (1911) suggest that rather dramatic declines in deer, elk, antelope, bison, wolf, and mountain lion have occurred since the settlement of European man. In 1905 wolves were reported in considerable numbers in the Piceance Creek valley. Mountain lions, according to the 1911 report, were eliminated from the Meeker region by trapping and poisoning.

Habitat types designated as major for the C-b Tract study area are chained pinyon-juniper rangeland, the pinyon-juniper woodland, the upland sagebrush, and the bottomland sagebrush. These major habitat types have developed on four major soil series which formed principally over three stratigraphic units.

The pinyon-juniper habitat has been altered to a more open habitat type consisting of grasses, shrubs, saplings, and slash as a result of the Bureau of Land Management's chaining of the pinyon-juniper woodlands on approximately 45 percent of Tract C-b. This increase in the rangeland habitat has favored livestock, deer, and small mammals, while decreasing available pinyon-juniper woodland for animals dependent on this habitat.

Large, predatory animals within the region do not demonstrate a distinctive association with a particular habitat type. Rather, they generally tend to range throughout most or all habitat types in search of suitable prey.

Coyotes, bobcats, weasels, and badgers probably range over the entire Tract C-b study area, where they feed primarily on birds, mice, rabbits, and ground squirrels. In terms of abundance, the coyote is probably the most important mammalian predator in the Piceance Basin and the study area. Both pinyon-juniper woodlands and chained pinyon-juniper areas contain a diverse population of small mammals, avifauna, and arthropods. Mule deer congregate in the agricultural meadowlands, alluvial areas, and in the lateral draws leading to uplands. The pinyon-juniper portions of the uplands provide food and shelter during the winter.

There is no perennial flowing or standing water within the Tract C-b lease boundaries. However, Piceance and Willow Creeks and ponds formed by their tributaries are within the extended study area. The largest of these, Piceance Creek, can be characterized as a cold water stream fed by spring and ground water, high in dissolved solids, with elevated nutrient and sulfate levels that become more concentrated toward its confluence with the White River. Low temperature and fairly high dissolved oxygen levels furnish a wider diversity of aquatic fauna than one might expect for a stream of such chemical characteristics. Eight species of fish have been reported from Piceance Creek near the Tract, including three species of trout. The most common fish observed are mountain suckers, speckled dace, and brook trout. Piceance Creek is the only known location for the mountain sucker in Colorado.

No threatened or endangered flora or fauna have been observed as residents on Tract C-b or the surrounding one-mile study area. Migrating birds designated as threatened or endangered (whooping cranes, greater sandhill cranes, and American peregrin falcons) may be periodically sighted in or around Tract C-b but none are considered residents or have been observed nesting on the Tract or study area. The mountain sucker found in Piceance Creek is considered unique to Colorado because of its disjunct distribution, but is not considered nationally threatened or endangered since it is common farther north and west.

2.3 Cultural Setting

The scenic evaluation program for Tract C-b emphasizes the disciplinary interactions which have been observed during the baseline study. Runoff of melt water and rainfall is responsible for stream flow as well as the general form of the area. The form or physical features of the area are the basis for the methodology in the U. S. Forest Service's Visual Management System which was used in the study of the scenic value of the Tract. The study, which also considered vegetal and hydrologic forms, found only one distinctive feature of the landscape in the Tract vicinity, i.e., the cliffs at the mouth of Scandard Gulch. This form is also the type locality for the "Scandard Gulch sandstone" which was used as the marker bed in conducting the surface-geology, mapping program. Furthermore, this same outcrop plays a role in forming lateral draws, one of the more interesting habitat types designated within the Tract study area.

From a cultural standpoint artifacts found by archaeological investigators suggest that man had used the Piceance Basin for hunting and gathering roughly 7000 years ago. The Basin was never occupied more than lightly. Prior to the middle to late 1800's little is known about human habitation in northwest Colorado. However, since about the turn of the present century the cultural environment is fairly well documented. During the last half of the 19th century railroads, herding, and mining have contributed to the growth of the area.

Although the economic fortunes and the population have fluctuated over the past 70 years, the present inhabitants look forward to improving the economic base of the Piceance Basin in such a manner as to preserve the natural and cultural environment that originally drew them or their ancestors to this region.

The Environmental Baseline Program for Hydrology included the measurement of flows in streams and springs and water levels in the various aquifers as well as the collection of water samples for analysis of constituents. A description of the parameters measured and the water sampling schedules are given in Volume II, Chapter 2. In Chapter 3 of this volume, the Baseline programs are discussed individually. These include the surface water program, the ground water program, and correlation-modeling studies generated in the ground water program. Chapter 4 of Volume II discusses utilization of the data gathered over the baseline period. This last chapter is intended to provide a basis for designing future monitoring and data gathering programs.

The C-b Oil Shale Tract is located in Rio Blanco County, Colorado, a little southeast of the center of the Piceance Creek basin (Figure 2-1). The Piceance Creek basin is the name given to a topographic basin area that is delimited by the outcrop of the Green River Formation. This area is part of the large structural basin also called the Piceance Creek Basin. To distinguish between these two areas, the structural basin is referred to as the upper case B-Basin and the topographic basin is referred to as the lower case b-basin. This somewhat confusing terminology is compounded further by the fact that the Piceance Creek basin covers two separate river drainage systems -- the Piceance Creek system and the Yellow Creek system. Tract C-b is located on the Piceance Creek drainage system and is bordered on the north by the Piceance Creek valley.

While stream flow is continuous along the mainstem of Piceance Creek and the lower reaches of some of its major tributaries, it is ephemeral in the upper reaches of major drainages and all side-gullies and tributaries. Stream baseflow, which amounts to more than one-half of the total flow, comes from the ground water rising to the surface at seeps and springs and through the alluvium. Peak flows occur during the early spring as rising temperatures cause the snow to melt. This snowmelt peak occurs from March to May. Isolated flow peaks occur throughout the summer months in response to convective thundershowers. Minimum flows are recorded during the growing season when diversions for irrigation deplete the flow.

In addition to the reduction in flow, irrigation affects water quality. Noticeable increases in total dissolved solids can be seen in the waters of Piceance Creek below the Tract during the irrigation season. The waters of Piceance Creek are somewhat unusual in that two anions are nearly equally dominant, i.e., both bicarbonate and sulfate are present in moderately high concentrations. Also, contrary to general experience with western surface waters, magnesium is present in higher concentrations than calcium. No reason for the anomalous dominance of magnesium is apparent. It could be attributed to leaching of magnesium from the marlstones found in the Uinta and Green River Formations. The increase in nitrates and nitrites during the irrigation season is attributed to livestock wastes and fertilizers in the irrigation return flow. A corresponding increase in dissolved solids, sulfates, and sodium is attributed to concentration by the reduction in flow, ionic exchange within the soils being irrigated, and an increased proportion of ground water in the surface flow.

The increase in the concentration of sulfate in the waters of Piceance Creek from 164 mg/1 upstream of the Tract to 290 mg/1 downstream of the Tract is attributed to the high sulfate waters contributed by two tributaries, Stewart Creek and Willow Creek. The same is true for other major ions such as calcium and magnesium.

A correspondence between the concentrations of major ions in seeps and springs and in the surface waters of Stewart Gulch and Willow Creek shows the reliance of these tributaries upon ground water contributions for their perennial flow. Except for bicarbonate, there is a good correspondence also with the mean concentrations of ions in the alluvial wells.

There is, however, no comparable correspondence between these water sources and the deep aquifer above the Mahogany mining zone, referred to as the upper aquifer.

Water samples were collected from the aquifers on a regular basis and from all water zones during the drilling of the core holes and test wells and during a series of aquifer tests. These aquifer tests consisted of two pumping tests (one for the upper aquifer and one for the lower aquifer), a mini pumping test, and a series of drillstem tests. The tests were designed to establish data on the physical characteristics of the aquifers and to investigate the presence of a series of aquitards. These data were necessary to formulate water management plans, to aid in mine design, and to test hypotheses concerning the effect on flow in aquifers and surface streams during mining operations.

Another characteristic important to the hydrology of an area is precipitation. Precipitation records from the microenvironmental studies, from the air quality program, and from the surface hydrology program are incorporated within Volume II. Precipitation is the driving force for the hydrologic system, whether it is expressed as runoff to surface water within a short time of the precipitation event, or whether it is finally expressed as baseflow from ground water supplies months and years after the precipitation event. In this regard, it is interesting to study the surface water flow by seasons and by yearly average. Unfortunately, data are limited and the longest record on Piceance Creek includes only 11 years of observations. If a longer record were available, a relationship between precipitation and surface water flow could possibly be developed. As it is, with only two years of record on the Tract and only 11 years on Piceance Creek itself, such anomalies as the apparent doubling of flow after the nuclear blast of Project Rio Blanco May 17, 1973 cannot be fully interpreted.

A facet of precipitation behavior that has begun to be investigated only recently is the effect on water and soils brought about by chemical constituents in precipitation. Research seems to indicate that such effects are greater in the summer during violent updrafts and subsequent convective storms than in other seasons when frontal storms dominate. Enough data are available on the Tract to be able to see minor effects on stream chemistry due to precipitation. One event in particular is discussed when rain fell on frozen ground in February 1976.

Results of the two-year Environmental Baseline investigation have delineated the major hydrological parameters for Tract C-b. These include stream flows, precipitation, water levels, and water quality. Some of the more significant findings are summarized below.

Stream flows in Piceance Creek upstream and downstream from the Tract, and in the two perennial tributaries bordering the Tract exhibit large seasonal variations and are strongly affected by diversions for agricultural use. Flows in the normally dry tributaries which drain the Tract itself are very rare, and have been observed under natural conditions only following heavy rains.

Stream flow data gathered prior to the C-b lease suggest that a large instantaneous increase in baseflow occurred in 1973 as a result of the Project Rio Blanco nuclear detonation a few miles from the Tract. Since that time, flow has gradually been returning to the pre-test conditions, so that the two years of Environmental Baseline data have been gathered on a declining curve.

Data obtained on flowrates of springs near the Tract have been inconclusive in establishing an annual cycle. Some springs do exhibit cyclic behavior. Data from other springs are incomplete because of agricultural diversions around the measuring flume in summer. An insufficient record is available for the pre-lease period to evaluate effects of the Project Rio Blanco detonation.

Water quality in Piceance Creek is a strong function of flowrate. Water quality is generally degraded with increasing distance downstream. Some changes due to specific inputs from tributaries have been identified, but the general increase in dissolved solids accumulates from non-point sources.

Samples from various springs were found to be quite similar in most respects. Highly saline springs, which are known to occur elsewhere in the basin, were not found. Concentrations of most constituents are in the same range as is found in the surface streams and the alluvial ground water. It was impossible to identify the source(s) of the springs by chemical analysis, but the lack of high fluoride levels would seem to indicate that these particular springs do not arise from the deep aquifers.

Water levels in the alluvium of Piceance Creek and its tributaries go through seasonal fluctuations as a result of spring snowmelt and summer rains. No significant direct pumping from the alluvium is known to occur. Some wells exhibit larger variations in water level than others, but the cause is not apparent.

Water samples obtained from alluvial wells exhibit the same general increase in dissolved solids content with downstream distance as is seen in the surface streams. However, there was no correlation between water quality and the seasonal cycles in water levels. This may be due to the way in which the alluvial wells were designed and the position in the aquifer from which samples were withdrawn.

Water level measurements in the deep aquifers confirmed the regional potentiometric contours previously established by USGS studies. No annual cycles were discerned. Some apparent anomalies in the data could not be completely resolved. One such indication is that of a "hill" or "mound" of water near the center of the Tract. This could be due to aquifer recharge by infiltration from the surface, or to increased vertical permeabilities along the lines of perennial stream flows, or to combined vertical and horizontal anistropy of permeability.

A second area of anomalous behavior is the generally increasing water level observed over the period of baseline observations. This could be a result of reaction to increases in precipitation and/or infiltration in the aquifer recharge areas, or of recovery from effects of the Project Rio Blanco detonation, or of changes caused by aquifer pumping tests and by open well bores in the Tract area. Calculations were made which showed that well bores in the Tract area which have been left open to both the upper and lower aquifers for a period of years could have a large effect on water levels in wells some distance away.

Water in the deep aquifers was found to be universally high in fluoride content. Just above and below the Mahogany zone, the total dissolved solids content is similar to that in the springs and surface stream. TDS increases with depth below the Mahogany zone and at greater depths there is an interval of extremely saline water. Some wells which penetrated this zone provided a path for migration of this saline water upward into the overlying aquifers. After this situation was detected, the wells were reworked to eliminate the inter-aquifer connections. Sampling from the wells after recompletion showed a gradual reduction of salinity in the affected aquifers.

In an attempt to define the sources of spring flows and the degree of interconnection between aquifers, a statistical comparison was made between water quality parameters for springs, the alluvial aquifers, the upper aquifer, and the lower aquifer. The results indicated, on a statistical basis, that each system comprised an independent population. It was not possible to define the source of spring flows from these data.

Aquifer pumping tests were conducted to determine basic hydrological parameters for the aquifers. Other data were then used to calculate the rate of water inflow to an underground mine and shafts. Several different organizations and types of computer simulation were used in this effort with widely varying results. The latest efforts have indicated that inflow to the mine will be considerably less than had been predicted by early studies of the problem.

The Environmental Baseline Program for Meteorology, Air Quality, and Noise included monitoring air quality over the entire two years of the baseline at five locations. Gaseous concentrations were monitored for sulfur dioxide, hydrogen sulfide, total hydrocarbons, methane, non-methane hydrocarbons, carbon monoxide, oxides of nitrogen, and ozone. Suspended particulate concentrations have also been monitored. A meteorological tower was utilized with multilevel instrumentation for measurements of wind speed and direction, relative humidity, and temperature. Upper air studies (temperatures and wind profiles), visibility studies, and noise studies were also conducted.

To satisfy the conditions of the lease and provide additional data, five air quality trailers, a 60.9 m (200 ft) meteorological tower, three mechanical weather stations, two acoustic sounders, aircraft, free-flying and tethered balloons, special chemical analyses for trace metals, visibility by photometry and sound-level measurement techniques were utilized. This represents one of the most complete data bases collected to establish a baseline against which to compare potential future changes.

Air quality monitoring is required under the lease stipulations, as well as under Federal and State of Colorado regulations. Several air quality permits were required during the course of operations; examples include a permit to construct the facility and to emit specified pollutants. The permit to construct requires computer modeling of shale-plant pollutant diffusion parameters to demonstrate compliance with prevention-of-significant-deterioration regulations for both sulfur dioxide and particulates. These regulations are so stringent that no significant air pollution impacts can occur.

4.1 Meteorology

The meteorological program was conducted utilizing a 60.9 m (200 ft) instrumented meteorological tower and other measuring instruments. A study of wind fields has been undertaken to determine how they would affect transport and diffusion of pollutants. Wind persistence by atmospheric stability class is an essential input to diffusion models. Winds in the vicinity of the Tract are influenced by both large-scale synoptic effects and small-scale local terrain effects with the latter usually more important. Patterns are diurnal in nature with flows downhill and down-creek at night and uphill, up-creek in the day with channeling by valley walls a major influence. Flows in general are neither uniform nor straight. Predominant wind direction on Tract at the tower is south-southwest. Peak 5-minute wind speeds have reached the 90 to 96 km/hr (56 to 60 mph) range only twice at the 60.9 m (200 ft) level in two years; the probability that a 5-minute gust will exceed 64 km/hr (40 mph) is 1.8×10^{-4}. Vertical wind structure is often far from uniform in direction; it generally increases in speed as height increases. On one occasion during tethersonde tests southerly winds at tower level have changed to calm between 213.3 to 335.2 m (700 to 1100 ft) and completely reversed direction to northwesterly above that level.

Annual temperature ranges of 65°C (150°F) have been achieved at the Tract, from about 37°C (100°F) highs in the summer to -45°C (-50°F) in the winter. Inversions have formed at night due to intense radiational cooling. Inversions occurred on most days in the vicinity of the Tract, usually starting in the early evening and dissipating by mid-morning; inversions were stronger in Piceance Creek than on the Tract proper. They often occurred to heights of 304.8 to 365.7 m (1000 to 1200 ft) above the Tract surface; mean inversion height at the tower was 220.3 m (723 ft). Inversion durations were longest in winter (13 to 14 hours) and shortest (5 to 8 hours) in summer. Strong horizontal temperature gradients (17 degrees in 6.4 km [4 mi]) have been noted in Piceance Creek in the presence of inversions, particularly when the inversion has started to lift at one locale but is still strong at the other end of the horizontal strip.

Atmospheric stability has been derived primarily by tower incremental temperature techniques, characterizing low level pollutant releases. Class D (neutral stability) occurred most frequently. Highest percent of stable class F (29 percent in 1975; 21 percent in 1976) occurrs in late summer to early fall. Stability assessment characterizing high altitude pollutant releases 182.8 to 304.8 m (600 to 1000 ft) have been made on a selective basis utilizing aircraft and tethersonde data. Only during the summer quarter of aircraft sampling did F-stability exist at altitudes up to 304.8 m (1000 ft); the tethersonde did not yield any stability class higher than D at a 182.8 m (600 ft) level at the tower on an hourly basis averaged over the test span.

4.2 Air Quality

Average background concentrations of all gases are fairly low, though infrequent high concentrations do occur. Readings in excess of standards have occurred for particulates. Some high ozone readings have been shown to correspond with either frontal passages during which ozone from the stratosphere is mixed downward, or long distance transport from urban centers (Las Vegas, Salt Lake City) or both. Others correspond to local sources. Particulates at the C-b Tract are primarily of fugitive origin. This was reasoned from the facts that high particulate loadings correlated best with maximum daily wind speed and that the 24-hour peak-to-annual-mean particulate ratios at the Tract were shown to be 3-4 times higher than ratios measured at an urban non-fugitive particulate station. The mass density of particulates in the respirable range has been shown to be approximately log-normally distributed. It has been shown that most particulates at the Tract are of sizes larger than respirable.

Trace elements in suspended particulates have been studied by spark-source mass spectroscopy and volatile trace elements (selenium, mercury, particulate arsenic, and arsine) were studied by specialized chemical methods. Low levels are indicated in practically all instances. Some difficulty was encountered in measuring arsine (AsH_3), particularly during the first year, due partly to the compound's interaction with particulate matter; the second year particulate arsenic was determined separately, and arsine concentrations were estimated to be below 0.5 $\mu g/m^3$.

Area wide visibility measurements were made every sixth day for one year. Mean visual range was 127.1 km (79 mi); 95 percent of the measurements exceeded 65.9 km (41 mi). Daily mean visual ranges exhibited large fluctuations, especially in fall and winter; variations of 48.3 to 64.4 km (30 to 40 mi) were common. A statistical correlation study of visual range with other parameters yielded the result that relative humidity correlated best; ozone was the second most important parameter.

4.3 Noise

The State of Colorado obtained traffic levels in 1974 at 13 stations in the general area of the Piceance Basin and in the towns of Rangely, Meeker, and Rifle. This approach derives traffic noise levels from traffic densities at specific density-measurement sites in the Piceance Basin.

A Piceance Basin traffic noise study indicated that Highway I-70 east and west of Rifle proved to be noisiest with a sound level of 66 dbA exceeded 10 percent of the time; three sampling stations along Piceance Creek road were the quietest sampling locations with only 53 dbA exceeded 10 percent of the time.

Representative background noise level measurements in the vicinity of the C-b Tract including locations along access roads and along Tract boundaries have been measured. These measurements were made one day per month at 14 locations over a 14 month span starting in September 1975. A General Radio 1565 sound·level meter has been used to obtain measurements. In general, environmental baseline noise levels in the vicinity of the Tract have been low.

The Ecological Studies portion of the Environmental Baseline Program was designed to describe the predevelopment, biological environment within the study area, and to provide baseline data to be used in monitoring changes in the biota as a result of oil shale development. The studies were also designed to meet the lease requirements and conditions of approval as stipulated by the Area Oil Shale Supervisor.

Parameters selected for study were principally system component variables (i.e., biomass, densities, abundance, temperature, precipitation, and soil moisture) rather than processes (i.e., photosynthesis, nutrient flow, herbage consumption), although some process parameters were studied (litter decomposition, plant productivity). In addition to the usefulness of the selected parameters in describing the existing environment on Tract C-b, consideration was given to their potential value in a monitoring program. Thus some parameters were judged to be useful only for describing the existing environment, while others were chosen as useful in monitoring because of their relatively low natural variability, relative ease of measurement, and/or sensitivity to expected environmental perturbations.

The Piceance Basin is a transition zone between the cold desert floras of the Great Basin and Intermountain West, and the montane forests of the Rocky Mountains. It is dominated by a pinyon-juniper ecosystem of open woodlands and shrub communities. The regional vegetative types which characterize the Basin were differentiated in the Pleistocene and have remained relatively unchanged to the present day.

5.1 Microenvironment

Studies on microenvironmental parameters on the C-b Tract provide data that are useful in assessing changes in vegetation structure, animal populations, or animal activity patterns, and may also be correlated with changes in functional components of the C-b ecosystem that may occur as a result of shale oil development.

Microenvironmental studies were begun in March 1975. Twenty-one stations were established: four continuous recording sites and seventeen non-recording spot check stations. The four recording stations were located in the four major vegetation types. Various physical parameters were measured. Temperatures began warming in April with peaks in August and September and then declined. Yearly maximum temperature reached a mean value of 49^{o}C (120^{o}F); the mean minimum was -17^{o}C (1^{o}F). Solar insolation appears to be the driving force for the differences in growing seasons between community types, and the effect of insolation is strongly influenced by the structure of the vegetation. Precipitation is greatest in winter, averaging 31 mm (1.22 in) per month. Periods of most significant moisture accumulation were May-June and January-March with 84 mm (3.3 in) and 170 mm (6.7 in) respectively. The late spring, early summer accumulation is significant for resumption of plant growth. There was a marked difference in precipitation patterns between the two years studied. Precipitation during the first year of the baseline, 1975, was greater during the summer months than it was in 1976. Precipitation during this second year was pronounced in early spring and notably low during summer. Soil water potential was lowest in woodland communities at -40 bars; chained rangelands also experienced relatively low levels of soil moisture tension (-25 bars), a condition that may be limiting to some species. In bottomland and upland sagebrush communities, soil moisture did not drop below -15 bars until late summer or early fall.

Statistical analyses showed differences between the microenvironments of the stations and between the years studied. It was concluded that these differences were not due to total precipitation or soil moisture, but rather to the unique make-up of each vegetation type (i.e., vegetation and soils).

5.2 Soils

The soil studies provide extensive data on nutrient availability; toxic levels of some geochemical constituents; soil productivity based on a standard laboratory seed stock; and soil biota, including bacteria, actinomycetes, and fungi.

Soil studies were conducted to determine correlations between soil constituents and vegetation. Studies included soil surveys and mapping, examination of soil nutrients, determination of soil productivity, soil-plant interrelationships, and soil-biotic studies.

Seven soil series were identified from the Tract and mapped. Chemical and physical characteristics of the soils were analyzed. In productivity studies, no differences were noted between the soil types with respect to germination. However, growth and biomass accumulation were significantly higher in two types of soil (Redcreek - Rentsac Complex). There were no strong trends noted between species and soil characteristics. There appeared to be marked differences between woodland and range sites as a group and big sagebrush as another group. Chained rangelands were the most productive sites, attributed to the higher concentration of soil microorganisms in this vegetation type. Soil characteristics (chemical analyses) showed differences within the soil type and vegetation community classifications. In soil to soil interactions, inhibitory interactions that establish limiting soil nutrient factors and a controlling influence of toxic soil constituents were noted. Limiting soil nutrients included phosphorous and potassium. Toxic soil constituents were salts, sulfate, and nitrate. Negative correlations and positive correlations were noted between these factors and certain vegetation species. In addition to interspecific competition, species tolerance and avoidance of certain environmental conditions were noted. Soil fungi were the most active soil microorganisms, with the greatest number found in surface layers. Actinomycetes were studied along with soil bacteria.

5.3 Vegetation

In order to provide an adequate baseline description of the existing vegetation, a number of component studies were conducted. These component studies included: the development of a floristic list of species present; phytosociological studies to determine structural features and distributions of the plant communities, and to provide validation for the vegetation map; productivity studies to provide background data on seasonal biomass accumulation, decomposition and litter fall studies to provide estimates of nutrient turnover rates and soil microorganism activity; herb phenology studies to provide developmental time frames of herbaceous species; shrub stem studies to provide seasonal change data on shoot elongation, flowering time, and senesence of major shrub species, as well as to allow evaluation of individual shrub responses to mule deer browsing activities.

5.3.1 Flora

Tract C-b lies in a floristic transitional zone between the Rocky Mountains to the east and the Intermountain West-Great Basin region to the west. The flora of the Tract is composed of approximately 230 species of vascular plants representing 54 families and 163 genera. Sixty-eight percent is composed of herbaceous perennials, although the Tract is characterized by pinyon-juniper woodland and open shrubland. No species identified from the Tract are considered to be endangered or threatened, and the flora of the Tract appears to be typical of the general region in western Colorado.

5.3.2 Plant Communities

Fourteen plant communities occur within the Tract C-b study area. These include:

5.3.2.1 Pinyon-juniper Woodland

Pinyon-juniper woodlands are the most common and widespread vegetation type in the Piceance Basin. Although over 50 percent of the original pinyon-juniper woodland on the lease Tract has been removed through chaining by the Bureau of Land Management, it is still one of the most common and dominant vegetation types on Tract.

The dominant tree species in the woodlands are pinyon pine, Utah juniper, and Rocky Mountain juniper. The composition of the shrub layer within the woodlands varies with slope and exposure, with big sagebrush dominant on the ridgetops; serviceberry, bitterbrush, and mountain mahogany dominating the hillsides; and snowberry dominant on north-facing slopes.

The pinyon-juniper woodlands are one of the most stable vegetation types in the Piceance Basin with the oldest trees being more than 200 years old. Pinyon pine and juniper do not appear to be invading other vegetation types.

5.3.2.2 Chained Pinyon-juniper Rangeland

Chained pinyon-juniper rangeland covers about 45 percent of the Tract and is generally restricted to ridges and gentle hillsides where bulldozer operation is feasible. The chained rangelands are ecologically unstable communities and are in early successional stages leading to reestablishment of pinyon-juniper woodlands. The dominant species include big sagebrush, bitterbrush, and saplings of pinyon pine and Utah juniper, with snowberry locally abundant.

Herbaceous cover in the chained pinyon-juniper averages 32 percent, approximately twice the value in the pinyon-juniper woodland. Common herbaceous perennials include Indian ricegrass, squirreltail grass, and western wheatgrass. Cheatgrass is the most common annual, but many other species also occur including goosefoot, stickseed, and tangy mustard.

5.3.2.3 Big Sagebrush Communities

Big sagebrush communities are widely distributed throughout the Piceance Basin and occur as two structurally different types.

5.3.2.3.1 Upland Sagebrush Communities

Upland sagebrush communities occur on broad ridgetops and in clearings within pinyon-juniper woodlands. The community is dominated by big sagebrush with occasional saplings of pinyon and juniper. Prickly pear is also common in many stands of upland sagebrush.

The herbaceous layer contains many species, including western wheatgrass, Junegrass, long-leafed phlox, hawksbeard, mariposa lily, clover, and microsteris, which occur at nearly 100 percent frequency. The upland sagebrush communities on Tract C-b apparently constitute a successionally-stable vegetation type.

5.3.2.3.2 Bottomland Sagebrush Communities

Bottomland sagebrush communities typically occur on valley floors and alluvial fans of the gulches throughout the Piceance Creek basin. The best developed bottomland sagebrush stands on Tract C-b occur in Scandard Gulch and along the West Fork of Stewart Creek.

The dominant species in these communities is big sagebrush with prickly pear and winter fat common in low densities. Other shrub species comprise a minor component of this association. The density of big sagebrush in the bottomlands is 1.7 times greater than that in the upland sagebrush communities.

The herb layer is dominated by the weedy annuals, cheatgrass, goosefoot, and stickseed, and the perennial mountain peppergrass, also a species characteristic of disturbed areas. However, the bottomland sagebrush community is not successional and disturbances to the association appear to favor the development of associations dominated by rabbitbrush rather than big sagebrush.

5.3.2.4 Douglas-fir Forests

Douglas-fir forests are a common vegetation type at higher elevations in the Piceance Creek basin. At elevations as low as Tract C-b, Douglas-fir stands consist of only a few scattered trees. They occur on steep north-facing slopes where more favorable cool and moist conditions prevail. Dominant shrub layer species include Gambel's oak and snowberry.

5.3.2.5 Mixed Mountain Shrublands

Mixed mountain shrublands represent some of the most widespread and abundant plant communities in the Piceance Creek basin. The mixed shrub communities are composed of numerous shrub species including Gambel's oak, serviceberry, mountain mahogany, bitterbrush, chokecherry, Juneberry, snowberry, and Oregon grape. The structure and composition of this vegetation type may vary considerably because many of these species may occur as the dominants depending on the slope, exposure, soil conditions, and moisture regime.

Herb-species composition is varied and includes numerous species characteristic of more mesic vegetation types. Low growing shrub species such as mountain-lover and Oregon grape are also common in the herb layer.

The mixed shrub communities in their typical form represent stable communities; successional changes are unlikely.

5.3.2.6 Bunchgrass Community

Bunchgrass communities occur primarily on steep talus deposits on the sides of major valleys. On Tract C-b, these communities generally occupy narrow bands between the bottomland sagebrush and the pinyon-juniper woodland.

The shrub layer in the bunchgrass communities is poorly developed with shadscale and four-winged saltbush occurring as dominant species in the stands along Piceance Creek. The herb layer is dominated by Indian ricegrass which reaches its maximum development in the bunchgrass community. Other common herb species include wild buckwheat, cheatgrass, and brickelbrush.

The bunchgrass communities on talus slopes are successionally stable, while those developed in other vegetation types following fire are successional and will eventually be replaced by pinyon-juniper woodland or upland sagebrush communities.

5.3.2.7 Marshlands

Because of the semi-arid nature of the Piceance Basin, marshlands are uncommon and occur only on floodplains of major drainages. Several small marshes occur within the Tract C-b study area, but none occurs within the Tract boundary. The vegetation in the marshes is composed primarily of perennial herbaceous aquatic and semi-aquatic plants. It is dominated by cattail, common reed, and numerous species of sedges and rushes with a few scattered, inconspicuous willows.

5.3.2.8 Riparian Communities

Riparian communities are located along the sides of the major streams in the region. Within the study area, the best developed riparian areas occur along Piceance Creek, Willow Creek, and the lower portions of Stewart Creek. There are no riparian areas within the Tract boundaries.

Riparian vegetation is primarily restricted to stream trenches except in those areas where the banks slope gently to the streambed. The vegetation along the streams is composed of sedges, rushes, horsetails, grasses, marsh elder, checker mallow, and others. Willows tend to be small and isolated and of limited occurrence.

5.3.2.9 Great Basin Wild Rye Communities

Prior to settlement of European man in the Piceance Basin, Great Basin wild rye communities occurred in dense stands on the floodplains of the larger streams. In the Tract C-b study area, Great Basin wild rye stands are restricted to small floodplain areas along Willow Creek and the East Fork of Stewart Gulch.

The dominant species in these communities is Great Basin wild rye with other common species being cheatgrass and mountain peppergrass. Big sagebrush also occurs occasionally in this vegetation type.

5.3.2.10 Rabbitbrush Communities

The distribution of the rabbitbrush community in the Tract C-b area is restricted to floodplain areas that have been disturbed since settlement. The rabbitbrush vegetation appears to be a successional vegetation type leading back to the big sagebrush vegetation type.

The shrub layer is dominated by rubber rabbitbrush with low numbers of big sagebrush as the only other shrubs in the vegetation type. The herb layer consists primarily of mountain peppergrass, western wheatgrass, and cheatgrass, with a varitcey of other weedy species.

5.3.2.11 Greasewood Communities

In the Piceance Basin, the greasewood community is restricted to valley bottoms and alluvial fans where local salt levels are high. In the Tract C-b study area, greasewood communities occur only on alluvial fans along Piceance Creek and constitute an ecologically stable vegetation type.

The dominant shrub layer species is greasewood with rabbitbrush as a secondary dominant. The herb layer is composed of relatively few species with the most common being cheatgrass and crested wheatgrass.

5.3.2.12 Agricultural Meadows

The agricultural meadows in the Tract C-b study area are restricted to floodplain areas along the major streams. These meadow associations are composed primarily of alfalfa and introduced pasture grasses.

5.3.2.13 Annual Weed Communities

The location of annual weed communities follows no pattern; rather, they occur on sites related to road construction, industrial development, or ranching disturbances. Dominant species on these sites include such weedy annuals as cheatgrass, white pigweed, tumble mustard, Russian thistle, and goosefoot. The most common perennials noted in disturbed areas were western wheatgrass and Indian ricegrass.

5.3.2.14 Aquatic Plant Communities

The ponds near Tract C-b support a lentic plant community dominated by pond weed (Potomogeton sp), and the Piceance Creek supports local concentrations of watercress.

5.3.3 Intensive Study Plots

5.3.3.1 Herb Layer Composition

Frequency data obtained over the two-year baseline survey indicate considerable consistency in frequency levels between years. Annual plant species as a group showed the greatest differences between the two years being more frequent in 1975 than in 1976. Estimates of total herb cover were comparable between the two years except for the bottomland sagebrush which was higher in 1975 than in 1976. The observed differences in frequencies can be attributed to both environmental (cooler and more moist conditions in 1975 compared to the warmer and drier 1976, and the occurrence of a killing frost in June 1976) and experimental (observer) error.

5.3.3.2 Shrub Layer Structure and Composition

Frequency values for most species were compared between the two years. In general, most sample sites increased slightly in cover from 1974 to 1976. Density values for some species, prickly pear and snake weed, were variable and big sagebrush and bitterbrush had higher densities while most species were not consistently higher or lower in observed densities over the sample period. Since significant shifts in shrub cover, frequency, and density would require more than two years, most of the variation observed should probably be attributed to sampling rather than to environmental changes.

5.3.3.3 Tree Layer

Tree growth at the intensive study plots was minimal during the baseling period with the utility of the data tempered by sampling difficulties.

5.3.3.4 Production Studies

While there were apparent differences in herb production between some treatments within the two chained rangeland plots, comparisons of peak standing crop data suggest few significant differences among treatment plots.

5.3.3.4.1 Herb Production

Comparisons of 1976 herb production in the major vegetation types on Tract C-b indicate that the upland sagebrush is the most productive (254±21 kg/ha/yr), followed by the chained rangelands (189±37 kg/ha/yr), pinyon-juniper woodland (132±22 kg/ha/yr), with bottomland sagebrush (113±20 kg/ha/yr) least productive. Differences noted in maximum standing crop between 1975 and 1976 indicate 1975 had a significantly higher productivity than did 1976. The difference between years appears to be related to temperature and precipitation differences during the growing season. Conditions were more conducive to plant growth in 1975 which tended to be cooler and more moist than 1976. In addition, a severe frost in 1976 apparently reduced the overall productivity of herbaceous species.

5.3.3.4.2 Shrub Production

Shrub production studies indicate that the bottomland sagebrush community is the most productive on the Tract (6929 kg/ha/yr). Mean shrub production was 17 times greater than production in the upland sagebrush vegetation type (415 kg/ha/yr), the second most productive type. The chained rangeland type was slightly lower in productivity (316 kg/ha/yr) than the upland sagebrush community, with the pinyon-juniper woodlands (91 kg/ha/yr) being the least productive community, in terms of shrubs, on Tract.

All sites show substantial reductions in shrub production in 1976 from levels achieved in 1975. As with herb production, the reduction in shrub productivity may be a result of differences in the temperature and precipitation regimes between the two years.

5.3.3.5 Decomposition and Litter Studies

In general, big sagebrush leaves appeared to decompose most rapidly followed by mountain mahogany, serviceberry, and then the cellulose standards. However, this may be a function of the size of the individual materials (i.e., the big sagebrush leaves were the smallest and the cellulose standards were the largest of the test materials).

No one community type stood out as having consistently higher or lower decomposition rates.

Litter fall studies indicated that litter fall is highly variable in its distribution on the ground, due primarily to canopy characteristics, with a seasonal range of 139±8 g/m^2 to 83±19 g/m^2 in some vegetation types. Turnover rates ranging from approximately 28 to 34 months were noted on Tract C-b. These rates may vary based on leaf tissue quantity and quality of soil in which the litter falls.

5.3.3.6 Herb Phenology Studies

There was a general tendency for a large percentage of the populations of perennial grasses to remain vegetative and produce few flowering heads. Forb species also produced few or no flowers during the sampling periods. The warm, dry growing season conditions may have been responsible for the limited flowering of perennial grasses and the very limited flowering of forbs.

5.3.3.7 Shrub Stem Growth Studies

Total stem growth of serviceberry was 3.1 to 4.6 times greater in the chained rangeland than in woodland sample plots. Apparent growth was greater in fenced than open plots. This difference may be attributable to browsing pressure by large herbivores.

Total stem growth of mountain mahogany was also greater in the chained rangeland than it was in the pinyon-juniper woodland. Within vegetation communities, the fenced plots exhibited greater stem growth than did the open plots. These differences in apparent stem growth may also be attributable to browsing pressure.

Stem growth studies of big sagebrush in both upland and bottomland sagebrush communities indicated that total stem growth in the fenced bottomland and upland plots was essentially the same. However, stem growth in the open bottomland plot was greater than that in the open upland plot. Within the upland site, stem growth was considerably greater in the fenced than in the open plot; within the bottomland site, stem growth was essentially the same in both plots.

The lack of differences between the fenced and open plots indicates that little browsing occurs in the bottomland plots, while at the upland site, there appears to be enough utilization of sagebrush to result in measurable difference between open and fenced plots.

5.4 Animals

Wildlife studies were conducted in compliance with lease stipulations and conditions of approval issued by the Area Oil Shale Supervisor. These included studies on: big game; medium-sized mammals; small mammals; birds; amphibians and reptiles; and terrestrial arthropods.

5.4.1 Big Game

Wildlife population levels prior to the advent of European man into the Piceance Basin are unknown. However, anecdotal information indicates that major changes in population levels occurred with major declines, as well as apparent recovery, in some important species such as elk, bison, mule deer, wolf, and mountain lion. Many of these changes are probably related to vegetation changes brought about by extreme overgrazing, and to various levels of hunting pressures on such species as the elk, bison, and antelope. The Piceance Basin mule deer herd is presently a major resource from a recreational viewpoint and therefore was a major focus of the C-b baseline big game studies. The studies of the deer herd activity within the Tract C-b study area included habitat utilization and movement patterns, as well as studies of mortality.

Mule deer are abundant on Tract C-b during winter, but are virtually absent in the area from mid-May to mid-September. During baseline studies, the height of the fall and spring migratory movements occurred on 18 October 1975 and 6 May 1976. Both dates are approximately one week earlier than were observed the year before. The duration of the fall and spring migratory movements, as observed on the study area, was approximately two weeks. Tract C-b is located within deer winter range and not on a travel route between summer and winter ranges. During winter, deer utilized chained rangeland more heavily than other habitats, but pinyon-juniper woodlands provided important cover as well as forage. Estimates of deer pellet-group densities were 377 and 475 per acre for the first and second year of baseline study in the chained rangeland habitat, and 260 and 373 for both years in the pinyon-juniper habitat. Differences between habitats during the same year, and yearly differences between the same habitats, were significant (P = .05). Shrub utilization studies indicated the deer population to be near carrying capacity. Shoot length measurements on antelope bitterbrush indicated 72 percent utilization in chained areas and 65 percent utilization in pinyon-juniper areas. Agricultural meadows north of Tract C-b attracted large numbers of deer in fall and spring, and nearby south-facing slopes were used by deer during times of deep snow. Road count studies indicated high numbers of deer near Tract C-b compared to most other areas along the 56.3 km (35 mi) length of road that was traveled. Deer were more abundant during the second year of baseline study as indicated by road counts and by pellet-group counts. Most winter deer mortalities occurred in the small lateral draws at lower elevations.

A few elk were present near the eastern boundary of the study area during March 1975. Elk fecal pellets were observed occasionally within the boundaries of the Tract, and most commonly in the pinyon-juniper and mixed mountain shrub habitats. Most fecal pellets observed were old and were not abundant at any site. Small groups of elk were seen on several occasions during July and August 1975 at higher elevations to the south of the study area.

5.4.2 Medium-sized Mammals

The study of medium-sized mammals was primarily oriented toward collection of data on presence and absence with estimates of relative abundance when the data allowed such analyses.

Coyotes were relatively abundant near Tract C-b compared to other areas in Colorado, Utah, and Wyoming. Indices of 188 and 122 for the first and second year of baseline study were obtained using the Fish and Wildlife Service scent station survey. The high numbers of coyotes may be partially due to the large amount of deer winter kill which occurs in the area and the minimal amount of local predator control. The importance of coyote predation on deer or other potential prey species was not determined.

Cottontail populations were judged to be low during the first year of baseline study compared to other areas in Colorado supporting satisfactory desert cottontail habitat. A noticeable increase was observed in the late summer of the second year, however. The habitat with the highest abundance of cottontails was the bottomland sagebrush, as indicated by track count surveys.

Information was limited regarding the abundance and distribution of the remaining medium-sized mammals identified on Tract C-b and precluded quantitative analysis. The remaining medium-sized mammals identified included the white-tailed jackrabbit, yellow-bellied marmot, muskrat, beaver, porcupine, bobcat, striped skunk, long-tailed weasel, raccoon, and badger.

5.4.3 Small Mammals

Small mammal studies on Tract C-b provide baseline data on a variety of population parameters for the most abundant species on Tract. The parameters analyzed include population densities, home range, reproduction, seasonal trends in abundance, longevity, food habits, and habitat preferences.

More species were trapped in chained pinyon-juniper (14) than in pinyon-juniper (7) or in secondary habitats such as pinyon-juniper rimrock, bottomland sagebrush, and mixed mountain shrub. The major factor contributing to this difference in small mammal diversity appeared to be habitat structure. In chained pinyon-juniper areas downed trees bulldozed into slash piles provided additional habitat for a variety of small mammals and an increase in herbaceous vegetation resulted from the removal of the pinyon-juniper overstory. The deer mouse and least chipmunk were the most widely distributed species and occurred in the majority of habitat types present in the study area.

For all species combined, the general pattern of seasonal density fluctuations was low density in early spring (10-25 individuals/ha; $\bar{x}$ = 18.1/ha), followed by an increase in number during summer (15-32/ha; $\bar{x}$ = 20.3/ha), and maximum densities occurring in late summer - early fall (25-55/ha; $\bar{x}$=32.5/ha). This general trend resulted from a combination of winter mortalities, spring reproductive effort, and late summer dispersal of subadults from spring litters. The deer mouse and least chipmunk were dominant species in terms of density, comprising 75 to 90 percent of the total density estimates in each trapping period. Voles, ground squirrels, and woodrats were less significant members of the small mammal community in terms of density.

Annual population fluctuations were also apparent from trapping results. Generally, the population changes were attributed to fluctuations in food supply and weather which varied between years. Differences were noted in the magnitude of annual fluctuations. The deer mouse and least chipmunk exhibited relatively low magnitude annual fluctuations, fluctuating by factors of 1.5 - 3.5 between years, while vole species and the Uinta chipmunk were subject to relatively high annual fluctuations (factors of 20 - 40). It was suggested that the magnitude of annual population fluctuations may be related to the relative sensitivity of species to factors which often act to control population growth, such as juvenile mortality, cessations of reproduction by adult females, and inhibition of reproduction in subadult females.

Although there was no significant difference in the total number of individuals trapped on Grid 1 (1113) chained pinyon-juniper and Grid 2 (1022) pinyon-juniper, differences in the abundance of certain species were noted, e.g., deer mice 453/Grid

1, 582/Grid 2; least chipmunk 408/Grid 1, 256/Grid 2. It was suggested that variation in habitat structure between Grids 1 and 2, which had a substantial effect on species composition, was also the factor most responsible for these density differences.

Reproductive efforts of species which produced multiple litters, i.e., deer mouse, voles, commenced in spring (May-June) and continued with varying intensity throughout the summer. Several other species (chipmunks, ground squirrels, and woodrats) produced only one litter per reproductive season in May-June. It was speculated that the initiation and success of reproductive activity was correlated to the presence of abundant green vegetation and favorable weather. The mean number of embryos (deer mice = 5.1; least chipmunk = 5.3) and placental scars (deer mouse 11.0; least chipmunk 5.6) correlated well with literature values.

Average live weights did not vary appreciably between years for the same species, age classes, and sex. Representative mean live weights were 21.5 gms for adult male deer mice and 33.0 gms for adult male least chipmunks; nonreproductive adult female deer mice 20.0 gms, nonreproductive adult female least chipmunks 34.0 gms. Because live weights were not subject to large magnitude annual fluctuations, it was indicated that long-term declines in average live weight might serve as a reliable measure of deterioration in habitat quality. In addition, live weights proved to be an accurate method of determining age classes for several species.

Home range size was calculated for the least chipmunk and the deer mouse. Representative home range sizes were 1.3 hectares for adult male least chipmunks and 0.63 hectares for adult deer mice. No difference in home range size was noted between Grids 1 and 2 for either species. There was some indication that subadults exhibited larger home range size than adults, and that home range size of males was larger than for females.

Survivorship and turnover rates of the deer mouse, least chipmunk, and Uinta chipmunk were calculated and appeared to be in agreement with documented survivorship for similar species. The mean survivorship of the deer mouse after first capture was 1.3 months and high turnover rates were common, indicating that this winter active species may be a significant prey item and subject to high rates of mortality during winter months. The least chipmunk and Uinta chipmunk exhibited longer survivorship (mean survivorship 1.6 - 1.9 months after first capture) and a lower turnover rate than the deer mouse. Their habit of remaining in their burrows for extended periods during winter months may have decreased their exposure to predators and unfavorable weather.

The relative frequency of diet items consumed by the deer mouse was generally correlated with the seasonal availability of those diet items. The relative frequency of arthropods consumed during spring and early summer ranged from 50 to 80 percent, while vegetation was the dominant diet item consumed during periods when arthropods were scarce. The least chipmunk was also termed an opportunistic feeder, but unlike the deer mouse this species consumed relatively large amounts of some diet items, e.g., seeds and vegetation, even when availability was low. This may have resulted from the least chipmunk's habit of storing seeds and other vegetation for consumption during winter months.

5.4.4 Birds

Studies of bird species utilizing Tract C-b on a resident, seasonal, or transient basis included seasonal censusing of songbirds, upland game birds, waterfowl, and raptors as well as defining the habitat requirements of the principal species within the study area. Major emphasis was placed on species most susceptible to changes in the environment that have limited distribution or have a relatively sensitive position in the food chain. Raptor species were among those analyzed in detail. Characteristics of the songbird, gamebird, waterfowl, and raptor segments of the Tract's avifauna are described on a seasonal basis, and species considered to be the most important structural and functional avian components of Tract ecosystems are designated. Population characteristics and habitat requirements are discussed for these species. A detailed description of census methodologies, a discussion on how data collected by the various techniques must be qualified, and a complete history of analyzed data on songbird-like species, waterfowl, and raptors is provided. Also, a listing of all species observed during the two-year baseline investigation program is included.

5.4.4.1 Songbirds

Although 136 bird species were observed within the study area during the 11 census periods, most songbird communities on the Tract are dominated by only two species, as indicated by a dominance index which summarizes relative densities for the two species achieving greatest numbers. At least 64 songbird or songbird-like species apparently nest on the study area. Substantial seasonal variations in density occurred for most habitats. The major factor which contributed to these variations was migratory behavior. Less than one-fourth of the songbird species which nest in the study area remain through the winter. Most of these species leave the Piceance Basin by late October and do not reappear until April or May. It was suggested that the high migratory propensity found operating on Tract C-b is generally typical of shrub steppe avifaunas, due to low supplies of winter food (principally seeds). Literature accounts support this speculation.

The greatest diversity of birds was reported during the late spring and early summer sampling periods; during this period, the diversity index (H') ranged from a low of 1.1 in riparian meadow (April 1976) to a high of 2.4 in pinyon-juniper woodland (June 1976).

Comparisons of density estimates for 1975 and 1976 breeding seasons indicated that densities for principal breeding species differed significantly between the two years in three principal habitats (riparian/agricultural meadow, pinyon-juniper woodland, and bottomland sagebrush, with reductions in densities in 1976 of 2.2, 2.4, and 2.4 birds/ha, respectively). These differences are felt to be attributed in part to decreased grass, forb, and shrub productivity, and to a decreased number of terrestrial arthropods during the 1976 breeding season, thus lowering food availability for both herbivorous and insectivorous birds nesting in the study area.

It is anticipated that species composition of the breeding bird communities will remain stable from year to year in the absence of major disturbances in all habitats except the chained pinyon-juniper woodland. There, normal vegetative succession is expected to influence changes in bird species composition and density as it did during the baseline investigations, when 11 breeding bird densities increased from 4.4 birds/ha in 1975 to 6.4 birds/ha in 1976.

Based on average densities of birds over 11 census periods, the pinyon-juniper woodland habitat supported the greatest number of birds (mean density 7.2 birds/ha); the riparian meadow habitat averaged the second highest density (6.6 birds/ha); while the upland transition habitat ranked the poorest (2.4 birds/ha).

5.4.4.2 Upland Gamebirds

Two species of upland gamebirds, the mourning dove and sage grouse, were observed in the study area. Sage grouse signs were observed only once during baseline studies. Mourning doves were recorded in every habitat on the Tract. Average nesting densities during the breeding season were highest in pinyon-juniper rangeland (0.2 birds/ha) and lowest in bottomland sagebrush (0.1 birds/ha). Flocking behavior occurring during the fall, resulted in high densities of mourning doves in the riparian meadow habitat along Piceance Creek (0.6 birds/ha).

5.4.4.3 Waterfowl and Shorebirds

Twenty-four waterfowl and shorebird species were recorded in the study area. Fifty-four percent are winter residents or migrants, and 11 species were found to be nesting in the area. During winter, mallard, green-winged teal, and American wigeon were the most abundant species in the Tract vicinity. The mallard and green-winged teal are also the only abundant permanent residents in the study area. Other common, summer-nesting species include: spotted sandpiper, Wilson's phalarope, and cinnamon teal. Waterfowl populations were concentrated along Piceance Creek and its associated ponds; however, the scarcity or absence of open water and aquatic vegetation limited waterfowl densities and usage in the study area. Waterfowl usage was highest on the P. L. Ranch pond where peak usage of 45.7 Average Bird-Use Days (ABUD) was recorded in the fall of 1974. Lower usage was recorded in the fall of 1975 (18.0 ABUD).

Results from the two-year waterfowl surveys indicated that waterfowl utilization along Piceance Creek is relatively high compared to other areas in the Piceance Basin.

5.4.4.4 Raptors

Eleven diurnal hawk, vulture, and eagle species; eight owl species; and the common raven were recorded in the study area. Nests of four of the 20 species (red-tailed hawk, golden eagle, great horned owl, and common raven) were located in the Tract vicinity. At least 12 other raptorial species are expected to nest in the region. Fourteen of the 20 raptor species recorded on the study area winter there. The rough-legged hawk, golden eagle, bald eagle, and common raven were the most abundant diurnal wintering species.

Most wintering diurnal species made extensive use of the riparian areas along Piceance Creek bottomland sagebrush and chained pinyon-juniper woodland, because of abundant prey and suitable hunting conditions. Dominant food items of wintering marsh hawks, buteos, American kestrels, and ravens were voles and deer mice. Density changes in these small mammals probably influence the size of local, diurnal raptor populations. Bald eagles and golden eagles apparently rely heavily on mule deer carrion and lagomorphs during winter, with the size of their wintering range dependent on prey density.

Red-tailed hawks, marsh hawks, American kestrels, ravens, and golden eagles were the most common diurnal raptors present during the breeding season. Nesting activity generally is initiated during March, and by April the majority of the study area's diurnal breeding raptors are present. Pinyon-juniper woodland and rimrock habitats provide the most abundant nesting sites within the study area. Summer food habit studies indicate that important raptor food items during the breeding season are voles, lagomorphs, pocket gophers, and deer mice.

Eight owl species were recorded in the study area. The great horned owl and screech owl were the two most abundant species observed, and both were recorded as permanent residents. Four other species (long-eared owl, short-eared owl, saw-whet owl, and pygmy owl) winter in the area in small numbers. Voles are the most common prey of owls based on food preference studies. In general, owls observed in the study area appeared to either overwinter in their summer nesting area or to migrate out of the region during severe winters.

5.4.5 Amphibians and Reptiles

Reptiles and amphibians were observed for presence or absence and, for selected species, relative abundance.

Reptiles were relatively uncommon in the study area. The relative abundance of reptiles observed on 2.72 hectare grids per observation period ranged between 5-22 with a mean of 11.6 on Grid 1 (chained pinyon-juniper) and 3-14 with a mean of 6.5 per observation period on Grid 2 (pinyon-juniper). Sagebrush lizards were the most abundant lizard on both Grid 1 (4-18/grid; $\bar{x}$ = 9.2) and Grid 2 (3-14/grid; $\bar{x}$ = 6.5). The higher relative abundance of lizards on Grid 1 was attributed to the increased diversity in habitat structure in chained pinyon-juniper due to slash piles.

Amphibians were also relatively rare in the study area due to the limited extent of aquatic habitat. The leopard frog was the most common species observed in the study area and appeared to be most abundant near Piceance Creek and agricultural meadows.

5.4.6 Terrestrial Arthropods

Ground dwelling and arboreal arthropods were sampled to provide data on relative abundance, habitat association, and seasonal population composition. Such studies provide information on relationships between arthropod species and various other components of the food web within the Tract C-b ecosystem.

The relative abundance of ground dwelling arthropods was generally highest in pinyon-juniper woodland during baseline studies (Grid 2 $\bar{x}$ = 51.5 individuals/100 pitfall days; Grid 1 $\bar{x}$ 26.5 individuals/100 pitfall days), while species diversity was highest in chained pinyon-juniper (Grid 1 $\bar{x}$ = 3.0075; Grid 2 $\bar{x}$ = 2.1255). Higher species diversity in chained pinyon-juniper was due to the presence of seven herbivorous arthropod species not observed in pinyon-juniper. It was suggested that a greater abundance of herbaceous vegetation in chained pinyon-juniper was responsible for the greater number of herbivorous species.

The diversity of arthropods collected from shrubs varied between major browse species with serviceberry ($\bar{x}$ = 2.8) and big sagebrush ($\bar{x}$ = 2.7) supporting similar diversities and mountain mahogany ($\bar{x}$ = 2.25) hosting a lower diversity. Many of the insects hosted by serviceberry were classified as defoliators.

These findings were consistent with published accounts of arthropod infestation of shrubs on western big game ranges which state that mountain mahogany appears to be relatively free of attack by insects and that serviceberry hosts numerous defoliators and stem insects.

Peak numbers of arthropods, 80 to 90 percent of which were classified as herbivores, were collected from all three major browse species (serviceberry, mountain mahogany, big sagebrush) during periods of maximum productivity. The occurrence of high numbers of arthropods was apparently related to the presence of succulent leaves and other plant parts. This finding was also consistent with previous studies which indicate that herbivore response to shrub phenology was the primary force influencing shrub dwelling arthropod numbers during the vegetative growing season. Late season productivity and delayed leaf senescence was apparently responsible for relatively high numbers of arthropods hosted by big sagebrush late in the growing season (September) when other shrub species supported relatively few arthropods.

5.5 Aquatics

The aquatic studies provide data on fish species, benthic macroinvertebrates, periphyton, and biologically important water quality parameters in the White River, Piceance Creek, and associated tributaries and ponds. Aquatic systems are sensitive to changes in salinity, pH, and other factors associated with the possible contamination of surface and ground water related to development of Tract C-b.

Aquatic studies were designed to provide data on water quality, sediments, plankton, periphyton, benthic invertebrates, fish species, and springs and seeps. Monthly collections were begun in August 1974. Sampling was reduced to a bimonthly program in January 1975 and continued through July 1976. Stations were established on the streams in the Tract vicinity (Piceance, Willow, and Stewart Creeks) and on the White River.

Water quality of the streams in the Tract vicinity was marginal with respect to recommended standards for aquatic life. At some time during the two-year study, 10 of the 31 water quality parameters examined exceeded the recommended limits for aquatic life referenced above. High runoff in the spring resulted in heavy siltation loads. In addition, irrigation practices and return flow altered normal flow rates and added to degradation of water quality.

Plankton were not analyzed during the study, except for light and dark bottle productivity estimates conducted in the lakes. Much of the phytoplankton that was present was the result of scouring of periphyton and was of minor significance with regard to primary productivity compared to periphyton and aquatic plants. Primary plankton productivity determined from lake stations was generally low, ranging from 0 to 213 mg C fixed/m^3.

Periphyton species collected consisted of green algae, diatoms, blue-green algae, and euglenids. The greatest periphyton abundance occurred in summer and fall. Productivity estimates were made for all stations, and ranged from 0.0067 to 4.1507 grams ash free dry weight/m^2 day.

Aquatic invertebrates collected at all stations were comprised of annelids, arthropods, and molluscs. Arthropods were most numerous. Species diversity, mean biomass equitability, redundancy, and dispersion values were calculated. These indicated the downstream portions of Piceance Creek were poorer habitat and supported less variety of species than the other portions of the streams studied. Based on Lagler's (1956) food grade categories, most stations were in the poor food grade the majority of the time. There were seasonal fluctuations in all of the species collected.

The most abundant fish species in the streams studied were: brook trout (*Salvelinus fontinalis*), mountain sucker (*Catostomus platyrhynchus*), and speckled dace (*Rhinichthys osculus*). Estimates of abundance per 100 meter stretch of stream ranged from 0 to 14 for brook trout, 17 to 101 for mountain sucker, and 7 to 115 for speckled dace. Brook trout abundance in the study area, based on tag returns, was estimated to be from 450 to 1,032 fish. Data on length-frequency, age, growth, fecundity, and food habits were compiled for the major species collected.

Twelve springs and seeps were identified and inventories of benthic invertebrates and water quality were conducted on a seasonal basis. Species collected were similar to those taken in stream studies.

The environmental stipulations of the Federal Lease require the Lessee to study and report on ecological interrelationships on the C-b Tract. The purpose of Volume V, System Interrelationships, is in part to satisfy this requirement. An ancillary purpose is to serve in conjunction with the utilization chapters of Volumes II, III, and IV, to provide insight into developing a monitoring program.

The System Interrelationships volume summarizes, integrates, and synthesizes much of the environmental information collected during the baseline program. It also provides information enabling a user to find specific data in the previous three volumes. This volume uses a holistic approach to describe the major interrelationships on Tract C-b. As such, it views the Tract as an environmental system divided into many interacting subsystems.

Volume V can be used in at least six different ways. First, this volume summarizes a great deal of baseline information in nearly 500 time-series graphs that depict behavior of many components and processes in the ecosystem over a two-and-half year period. Secondly, this volume serves as a cross-reference to Volumes II, III, and IV by referencing the original data from which the time-series summaries were drawn. A third use of this volume, and perhaps the heart of it, is to examine the conceptual model of the C-b Tract system. This conceptual model is systematically developed in the volume. A fourth way to use the volume is to track environmental impacts using this conceptual model. System diagrams display the conceptual interrelationships in the terrestrial and aquatic portions of Tract C-b in such a way that a user can begin to understand the far-reaching ramifications of an impact on one part of that system as it is felt throughout the rest of the system. This type of information, of course, provides insights into planning a monitoring program, a fifth way to use this volume. Finally, in the same way, one can postulate environmental perturbations caused by man and, using the diagrams, determine how widespread the effects of these perturbations will be, and thus plan mitigation of these perturbations.

Ecosystem components in Tract C-b were focused on in this volume. Out of the plant and animal species that were identified and studied, and of the many environmental parameters that were monitored during the baseline program, key structural components of the ecosystem are identified by aggregating and combining many of the individual components that were studied earlier. This aggregation is done to simplify analysis of the total system. For example, of the 14 plant community types that were identified during the baseline studies, five ecosystem response units are produced conceptually by aggregating some of the plant communities into one category based on similarity of vegetation and topography. These ecosystem response units are then related to the ecosystem components so that the components are associated with particular ecosystem response units. The time-variant behavior of the many ecosystem components is discussed in detail. This behavior was monitored during the baseline studies. In many cases, conceptually important components were not studied during the baseline period. However, estimates of the behavior of these components are also presented to round out the conceptualization.

Eighty-five significant ecosystem processes that control the flow of matter and energy among the components of the ecosystem and among ecosystem response units are identified. The concept of flow currencies, i.e., the materials of the units of energy that actually flow between components is introduced. Establishing the linkages formed by flow currencies, and identifying the processes that control these flows, sets the stage for constructing a holistic conceptual model of the ecosystem.

The above description deals primarily with the Tract C-b environmental system as it existed during the baseline studies. In addition, Volume V introduces the influences of oil shale development on the Tract. Using the detailed development plan documents to determine the phases and activities associated with oil shale development, sources of environmental perturbations that may be anticipated during the development are identified.

Next, the materials on ecosystem components, processes, and sources of environmental perturbations that may be anticipated during the development are synthesized into a holistic view of the Tract C-b environmental system. Five flow currencies are identified, namely: heat, water, animal numbers, animal weights, and plant carbon. Each currency defines a separate subsystem. The animal numbers flow, then, constitutes one subsystem; the plant carbon flow another, etc. These subsystems are further linked spatially by flows among the ecosystem response units. The dynamics of the Tract C-b system are thus considered over both time and space. Superimposed upon the structure of the system as it existed during the baseline studies are the oil shale development influences. The complex interactions among the processes, the ecosystem components, and human influences are all documented in a series of figures that describe the factors affecting different flows in both the aquatic and terrestrial systems. Another set of figures concentrates on each flow individually as it is affected by different factors in the system. An impact effects matrix further focuses on these interrelationships, identifying the elements of the ecosystem that impinge upon various processes, with special consideration for potential influence of oil shale development on the system.

The analysis is carried further by developing total system diagrams that depict how the components and processes are linked together within the subsystems and how the subsystems themselves are linked within the aquatic and terrestrial systems. These oversized figures can be used as wall charts to trace environmental impacts and other effects throughout the system.

Volume V further utilizes the materials developed previously to identify and discuss major ecological interrelationships on Tract C-b. It discusses the abiotic-abiotic, the abiotic-biotic, and the biotic-biotic interactions of significant elements within the system. Of the more than 900 effects identified in the major matrix, 28 major effects anticipated from oil shale development are addressed. Only a few of the broad implications of these effects are discussed.

Finally, ideas for utilization of Volume V in planning monitoring, and mitigation programs for the oil shale development are discussed. In addition, some suggestions are put forth for implementing numerically some portions of the conceptual model.

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